Measurements of Relative Permittivity and Dielectric Loss Tangent of Fodel Dielectric with a Split-Post Resonator

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Abstract

The increasing use of computer-based software packages for designing RF/microwave circuits requires very accurate data about dielectric properties of materials used in the design. This paper presents results of precise measurements of relative permittivity and loss tangent of alumina substrates and Fodel dielectric 6050 used in thick-film photoimageable technology for fabricating microwave double-layered circuits. Split-post resonator method has been used in these measurements.

1. Introduction

For numerous applications accurate permittivity and dielectric loss tangent characterization of flat substrates and planar, thin layers of dielectrics at high frequencies is critically required. Usually manufacturers provide data about dielectric properties of their products at frequency 10 MHz with rather large uncertainties. Nowadays the increasing use of computer-based software packages for designing RF/microwave circuits requires much more accurate data at much higher frequencies. The paper presents the results of measurements of e_r and *tand* of alumina substrates and Fodel dielectric with using a split-post resonator method.

2. Split - Post Dielectric Resonator

The split-post dielectric resonator (SPDR) technique allows accurate characterization of dielectric properties of materials at microwave frequencies between 1 GHz and 20 GHz. Typical uncertainties of relative permittivity for this technique are +/-0.5% and loss tangent resolution is in order of 1 x 10^{-5} [1].

The split-post resonator is a circular-cylindrical cavity that is separated into two halves. A sample is placed in the gap between the two shorted cylindrical waveguide sections (Fig.1). A coupling loop in each waveguide section excites a TE_{011} resonance, and from measurements of the resonant frequency and quality factor, the permittivity and loss tangent of the sample can be determined.

The advantage of the method is that the sample needs only to be planar and extend beyond the diameter of the two cylindrical waveguide sections. No other sample machining is necessary, making this method attractive for accurate non-destructive measurements of low-loss substrates [2,3].

The method can be adapted for measurements of properties of thick-film dielectrics deposited by screen printing on flat substrates (Fig.2). The substrate, which is the base for the tested dielectric, must be of low loss, low permittivity and extremely even thickness to make sure that the resonant frequency changes produced by the dielectric layer under test are larger than the resonant frequency changes caused by uncertainties of substrate thickness [1]:

$$\Delta h_s \le \frac{(e_f - 1)h}{e_s - 1} \tag{1}$$

where:

h_S and e_S are the thickness and relative permittivity of the substrate,

h and e_f are the thickness and relative permittivity of the tested layer,

Dh_S is the uncertainty of substrate thickness in the tested area.

Fig.1. Split- post dielectric resonator (19.6 GHz).

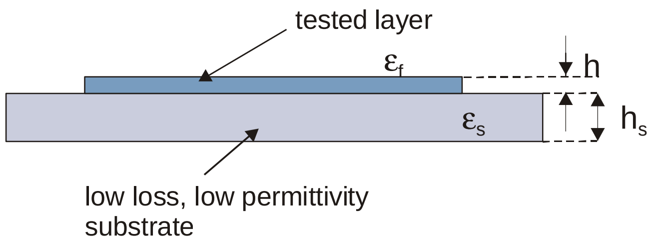

Fig.2. Test sample

The method is based on measurements of resonant frequency and quality factor of the empty resonator, the resonator with the substrate, and finally the resonator with the substrate and a dielectric deposited on top. Dielectric parameters of the tested dielectric are calculated on the basis of full-wave electromagnetic analysis [1,4,5].
The main source of uncertainty De_r includes errors associated with the uncertainties of sample and substrate thickness and accuracy of measurements of the resonant frequency. The uncertainty *Dtand* predominantly depends on uncertainty of Q-factor measurements and the ratio of losses in the sample under test to the losses in the substrate and in all other parts of SPDR.

3. Test Sample Preparation

Looking for thin, smooth and uniform substrates, fused silica, single-crystal quartz, and mica were initially tested as the proper base for Fodel dielectric 6050 (Fig.3). Typical for thick-films as-fired alumina substrates of thickness 0.635 mm didn't meet the requirement (1).
The initial attempts turned out to be a failure. Fused silica crashed into pieces at high temperature of a furnace for thick-films, Fodel dielectric exhibited poor adhesion and some disagreement on thermal expansion coefficients to crystal quartz (Fig.4), mica underwent lamination into thin sheets during firing at 850^0C (Fig.5).
Finally ultra-thin, polished alumina substrate of thickness 0.126 mm was taken as the best choice for further experiments (Fig.6). A circle of diameter 20 mm made of Fodel dielectric was deposited on this substrate by screen printing. The following technological sequence was used:

[PRINT / DRY] / [PRINT / DRY] / FIRE] x 2.

The profile cross-section of the deposited dielectric layer is shown in Fig.7 . The layer is of fired thickness 34μm and it is very smooth and uniform. The technological details of processing Fodel dielectric 6050 have been described in [6,7].

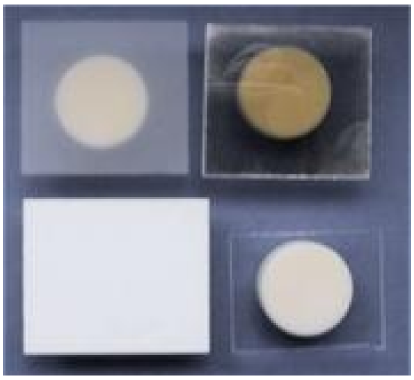

Fig.3. Substrates considered for Fodel dielectric deposition.

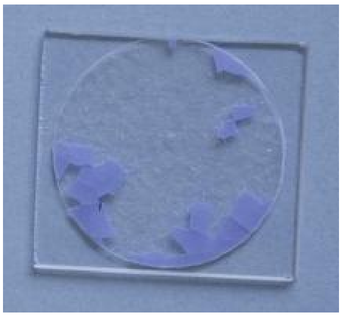

Fig.4. A faluire. Fodel dielectric on fused silica. Disagreement on extension coefficients.

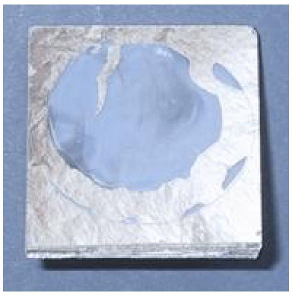

Fig.5. A failure. Fodel dielectric on mica substrate. Poor adhesion. Delamination of the substrate at temperature of firing.

Fig.6. The only right solution. Fodel dielectric on polished alumina substrate of thickness 126 µm

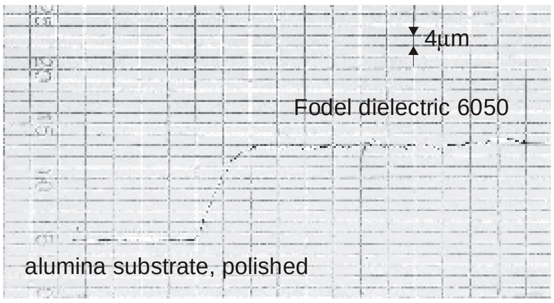

Fig.7. Cross-section profile. of Fodel dielectric on high quality polished alumina substrate of thickness 126 µm

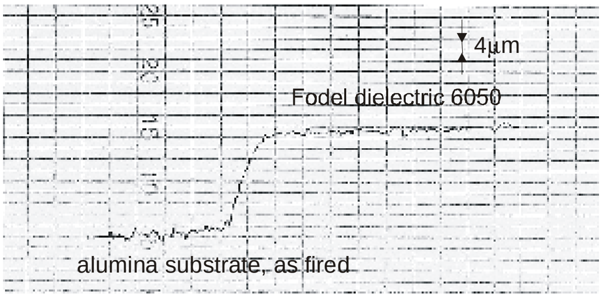

Fig.8. Cross-section profile of Fodel dielectric on as-fired alumina substrate of thickness 635 µm

4. Measurement procedure

The measurement system (Fig.9) used for the microwave characterization of the samples consisted of the Network Analyser HP 8722C and the split-post dielectric resonator. Resonant frequency and the loaded Q_L factor were measured by the Network Analyzer. Unloaded Q_0-factor was assumed to be the same as the loaded one since both couplings of the resonator were adjusted to be very low (S_{21}<-45 dB). In such a case, differences between the loaded and the unloaded Q-factors are below 1%.
Relative permittivity and loss tangent was calculated with a software method [1].

Fig.9. Measurement set-up.

5. Results

At first, taking advantage of the access to the measurement set-up at GHz frequency, measurements of e_r and *tand* of a few types of commercially available ceramic substrates (Al_2O_3 and AlN) were carried out. The results are presented in Table 1.
One can observe that permittivity of alumina substrate is constant versus frequency (within experimental errors) and that dielectric losses increase with frequency.

Table 1. Relative permittivity e_r and *tand* of ceramic substrates at various frequencies up to 20 GHz

Sample	*Thickness [mm]*	*Freq. [GHz]*	e_r	*tand*	*Manufacturer*
96%Al_2O_3 as-fired	0.620	5.4	9.091	4.90×10^{-4}	CeramTec
96%Al_2O_3 as-fired	0.616	19.2	9.105	6.94×10^{-4}	CeramTec
96%Al_2O_3 polished	0.126	9.9	9.230	6.30×10^{-4}	ACCUMET
96%Al_2O_3 polished	0.126	19.6	9.226	1.2×10^{-3}	ACCUMET
99.8 % Al_2O_3 as-fired	0.732	17.7	10.03	9.46×10^{-5}	Polish manufacturer
AlN	0.645	19.3	8.286	1.85×10^{-3}	CeramTec

Afterwards the Fodel dielectric properties at frequency 19 GHz was investigated.
Results of measurements with a vector network analyzer of resonant frequency f_o and Q_0-factor for the system: Fodel dielectric 6050 deposited on polished alumina substrate of thickness 0.126 mm are collected in Table 2. They were the basis for the extraction by the software analysis [1] relative permittivity and loss tangent of the Fodel dielectric 6050 (Table 3).
Uncertainty of thickness of the alumina substrates was established on the basis of multi-point measurements of their thickness (at four corners and at the center) using micrometer screw with resolution of 0.001 mm. Thickness of the Fodel dielectric layer was found with accuracy 0.001 mm on the basis of its cross-section profile made by Tylor-Stylus equipment.

Table 2. Measured resonant frequencies f_0, and Q_0-factors of the system: substrate+dielectric
(h_S - thickness of substrates, h –thickness of Fodel dielectric)

Measurement	f_0 *[GHz]*	Q_0	h_S (mm)	h (mm)
Empty resonator	19.6406	7 500		
Resonator with the alumina substrate	19.3347	5 750	0.126 +/-0.001	
Resonator with the alumina substrate and Fodel dielectric on top	19.2884	4 400		0.034 +/-0.001

Table 3. Extracted relative permittivity e_r and *tand* of Fodel dielectric 6050 (at 19.6 GHz)

Fodel dielectric 6050 deposited on:	e_r	*tand*
Fodel dielectric 6050 deposited on: 96%Al_2O_3, of thickness 0.126 mm	5.70 +/-3.5%	9.39 x 10^{-3}+/- 20%

Further tests with a low loss sapphire substrates plus the most precise positioning of the substrate inside the resonator are planned to continue.

6. Conclusions

Measurements of relative permittivity and loss tangent of Fodel dielectric 6050 at frequency 19 GHz were carried out. The investigations showed Fodel dielectric 6050 exhibits e_r =5.7 and $\tan\delta = 9.39$ x 10^{-3} at 19.6 GHz.

Demands for smaller and cheaper communication devices resulted in significant advances in manufacturing miniature 3-dimensional circuits. Advanced ceramic technologies such as Low Temperature Co-Fired Ceramics (LTTC) and photoimageable thick-film technology offer possibilities for manufacturing compact 3D microwave devices. However, under one condition. We have to know how to measure dielectric properties of materials – substrates and dielectrics – used in multilayer structures. The results of measurements of dielectric properties of Fodel dielectric will be used in design works of double-layered photoimageable thick- film microwave hybrids

7. References

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